CIRCULAR FOAM

Prototype of improved metal panel

Deliverable 2.2

Revised after review

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Technical References

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Executive Summary

This report details the outputs and work performed by Kingspan in support of Task 2.2. The main objective is to produce a prototype panel design that is easily dismantled for recovery and recycling of the components. It should be noted that this work runs parallel to Kingspan's own sustainability activities under the Planet Passionate programme (Kingspan, 2023); a 10-year plan to drive improvements in four target areas (carbon reduction, renewable energy, circularity, and water use).

In designing for circularity, a "form-follows-function" approach was taken where the facilitating ease of recovery and recycling was prioritised – though not at a level where safety and performance (particularly structural strength, insulation, and fire performance) were compromised. Proposed changes to panel materials, design and installation for the prototype panel were assessed via internal stakeholders with a view to maximising the potential while minimising the disruption to existing processes, the approach is outlined below. These modifications form part of the basis of the customer/stakeholder engagement currently ongoing under task 2.3 and will feed into work planned under WP6.

Approach:

- **State-of-the-art assessment of demolition of metal panel:**
  This will involve categorising the individual components that make up a typical panel, assessing the current status in relation to circularity and possible impact on foam recovery. Determining and, where possible, demonstrating changes what will facilitate improved circularity.

- **Circular Panel prototype design:**
  Based on the above, identify areas for design improvement and present a prototype panel to facilitate recovery while minimising the effect on panel performance.

- **Construction/deconstruction process (appendix):**
  A short demonstration of construction/deconstruction is provided in the accompanying video. And a brief overview of build methodology is provided in the appendix.

  video metal panel

Video metal panel (link to project website)

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1. State-of-the-art assessment of demolition of metal panel

In this section, the different components comprising current sandwich panel designs are described and their ease of processing considered. Though the main focus of the Circular Foam project is on facilitating easy recovery of the PIR foam for processing, the recovery and reuse/recycle of the other panel components and building materials are also considered. Any potential effects on foam recycling will also be assessed (e.g., contamination, loss of foam during processing, etc.). It should be noted that other design requirements will heavily influence the choice of materials and processes employed – particularly those relating to durability, fire safety and long-term performance. All these points will be considered in terms of the prototype design and improvements proposed or demonstrated where possible.

The PUR/PIR foam typically makes up the bulk volume of the panel and its recovery and recycling is one of the main goals of this project. The sorting and recycling processes are being investigated under separate work packages and though they will not be discussed in detail here, they will be considered in terms of the materials and design of the panel. In terms of the PIR foam, the optimum outcome is to allow for the maximum recovery from panels in the least labour, time and cost intensive manner. The other elements that make up a panel are discussed below in terms of their potential impact on foam recovery.

Steel:

Aside from the foam, the other main component of a sandwich panel is of course the steel sheets that give the panel its strength and protection. As noted above, removal of the steel in an efficient manner that minimises losses of foam (through disintegration and adhesion to the steel, etc.) is the priority. Infrastructure for steel recycling is widely available and well-established methods of removing and treating steel prior to recycling already exist. In this case, band or wire saws can be employed to separate the steel and foam while another approach involves physically ripping the steel from the foam. The accompanying video shows a panel being manually ripped (see video at 3:10 min) but this would not be done during a recycling process. Kingspan has previously investigated ripping methodologies and have employed both manual ripping and a semi-automated system involving a rotary drum for the removing of the steel layers (see figure 1 below). This system has a relatively small footprint and could in theory be deployed on site. It would not be suited for mass processing of recovered panel but does allow for assessment of different panel profiles and the ease of steel removal. In tests, panels with flatter profiles were found to be much easier to process compared with those with features (see figure 2). In addition, panel designs featuring crowns (common design employed to improve structural strength of roof panels) have proven more problematic when trying to remove the steel and the more complex profile can result in the foam being trapped in the feature during steel removal, complicating the recovery and potentially reducing the yield of recovered foam. Employing saws to separate steel and foam will also suffer from the same problems. These issues will be addressed in section 2 of the report.

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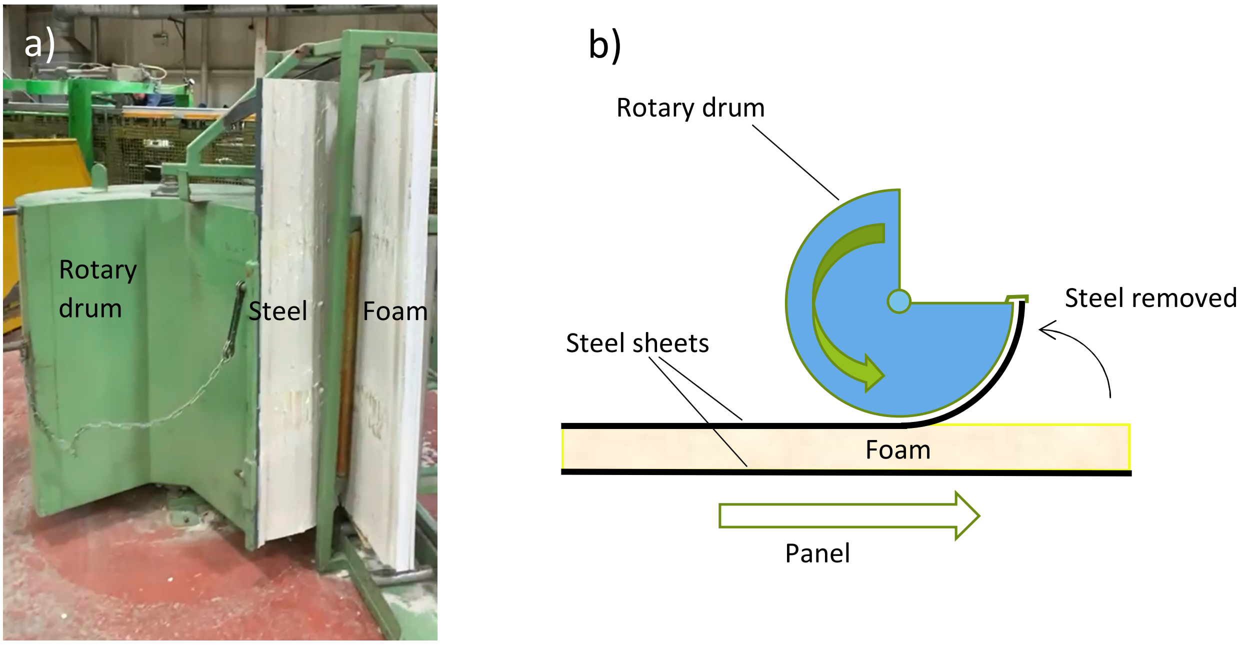

Figure 1. Semi-automated steel removal system (a) system in operation, (b) operation schematic (top view).

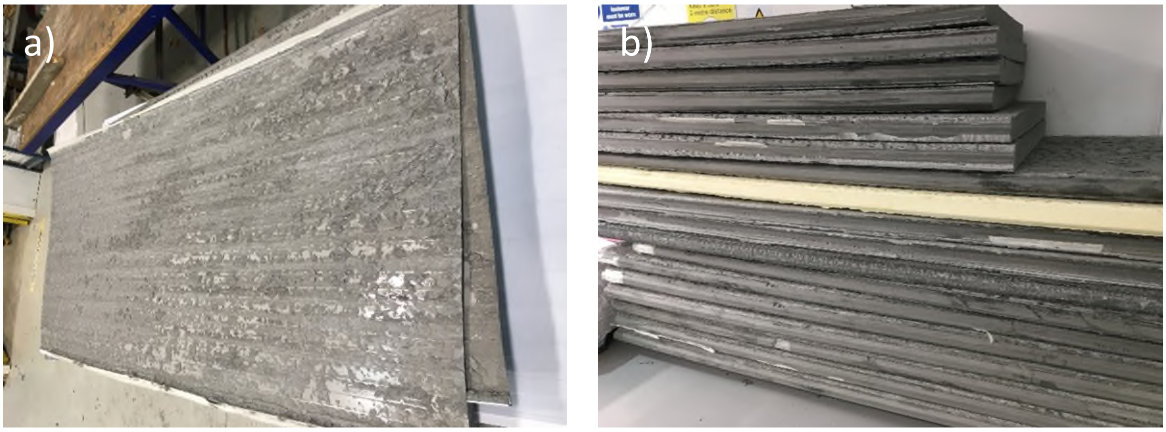

Figure 2. Steel sheets post removal. Thin layer of foam remains on the steel (a) – leaving the bulk foam block intact and ready for transport/processing (b).

Main points:

- Steel recovery is a mature process in many recycling facilities, already carried out to remove steel for recycling.
- Kingspan working with a supplier to deliver zero carbon processed steel for panel manufacture.
- Kingspan recently released a lower embodied carbon panel.
- When performed systematically with flat profile panels, recovered foam blocks typically remain intact for easy storage and transport.

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Side tape:

During fabrication, side tapes perform a vital function of supporting the panel during the manufacturing process. They also provide a secondary function of protecting the otherwise exposed foam prior to installation as well as branding etc. The side tape is typically a few 100 µm thick and is comprised of polyethylene or polypropylene. In the production process, the tapes are fed from side-rollers and connect to the top and bottom steel sheets as the reaction mixture is introduced onto the lower steel sheet.

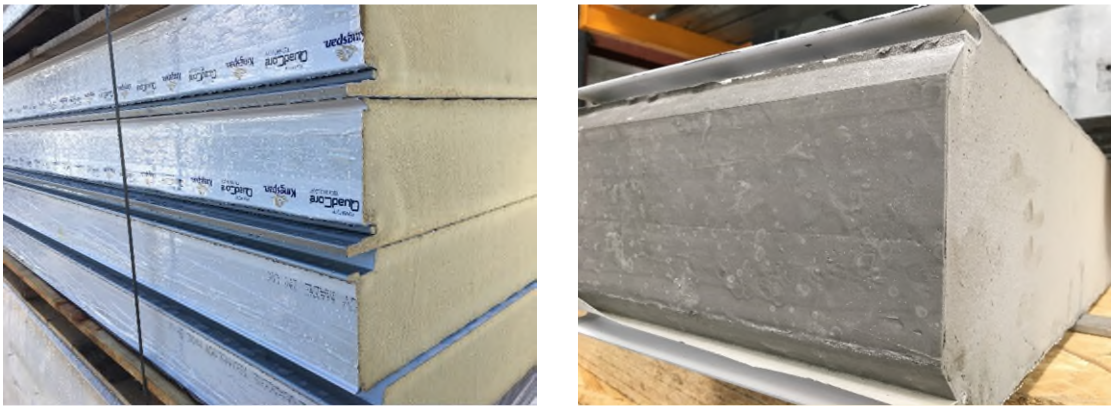

Figure 3. Line panels with side tape (a) and R&D panel manufactured without side tape (b).

R&D panels can be manufactured without side tape (figure 3b) but removing side tape from the production process would be very challenging and costly to accomplish on a continuous line. In line with Kingspan's Planet Passionate goals, efforts are focusing on sourcing tape from renewable sources and/or employing bio-based materials. However, regardless of its composition, the tape could still negatively impact the recovery of the foam during processing. At this point, it was decided to focus on facilitating trimming of the side tape from prototypes prior to the recycling process. The adhesion between tape and foam is typically quite strong and simply attempting to peel off the tape was highly inefficient and led to unsatisfactory results so other methods must be employed. Trimming the foam to remove side tape as part of the foam recycling pre-processing appears the most likely solution. The PIR/sidetape off-cuts could potentially be chipped and reused for low-value applications (packaging, etc.). The accompanying video includes a short demonstration of the tape being removed from a foam block via bandsaw (see video at 3:46 min) – note that only small volumes of foam are lost during this process.

Finally, it should be noted that in discussions with other consortium members, it was noted that the presence of side tape may not interfere with the pyrolysis-based recovery methods, but this will need to be investigated further to determine if this is the case, presumably under WP4 activities. In any event, removal of the tape prior to reprocessing of the foam is still considered the optimum approach.

Summary:

- Issue: difficult to recycle and difficult to remove (aside from cutting tape & foam via saw). Required for continuous line production of panel.
- Potential solutions for prototype:
  - ascertain if pyrolysis/chemolysis possible on foam containing side-tape residue.
  - manufacture panel without side tape (long-term goal)

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    - remove through trimming sides of recovered foam block prior to recycling (implementable solution at recycling facility).

Sealant:

Employed as weather/airtight sealing once panels are installed. This process is performed for both wall and roof panels and typically involves applying a robust, weatherproof material between the seams in the panel. Butyl-based sealants are the most commonly used for this application. These have the advantage of being largely solvent free.

- Issue: by design the sealant has to be a strong robust adhesive with an intended functional lifetime measured in decades. Debonding sealed panels will complicate the dismantling of more modern panel systems as the bond between panels will be quite strong.
- Use of sealants derived from more sustainable sources is a current aim of Kingspan. The long-term performance of any sealing material will have to be considered both in terms of building U-values and fire performance as well as the primary sealant function.
- The sealant may be a source of contamination, remaining in on the previously sealed surfaces of the foam. In this case trimming the foam block as described for the side tapes may be required.
- Potential solutions:
    - Trim any residual sealant from the panel prior to reprocessing (as performed for side tapes).
    - If required, effects of any potential butyl contaminant on foam recovery (pyrolysis/chemolysis methods) can be assessed.

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Fasteners & fittings:

Fastener removal during deconstruction is shown in the accompanying video. The fasteners, purlins, flashings, and other metallic fittings can be separated and sorted for recycling.

- Fully removed during dismantling, however broken screws, washers etc. may remain in place and have to be removed manually (see video at 3:03 min). Screening may be needed prior to foam recycling to ensure these contaminants removed.
- Can be rectified with improved fastener designs (ongoing).
- Alternative options not requiring fasteners are considered in the appendix.
- Solvable issue with screening.

2. Demonstration of design of a prototype

In addition to the materials employed in construction, modifying the design of the prototype was investigated to improve circularity – particularly in relation to simplifying the installation and facilitating panel deconstruction. Currently, a wide range of profiles/cross sections employed depending on application and aesthetic requirements and these were assessed for suitability for the prototype. The optimum design would be one that allows for simple deconstruction of the component elements (those as outlined above) and facilitate easy transfer to the reprocessing facility. The ideal prototype would have a completely flat profile (no crowns/trapezoids/etc.) and a graphic of the flat profile panel and desired characteristics are given below in figure 4.

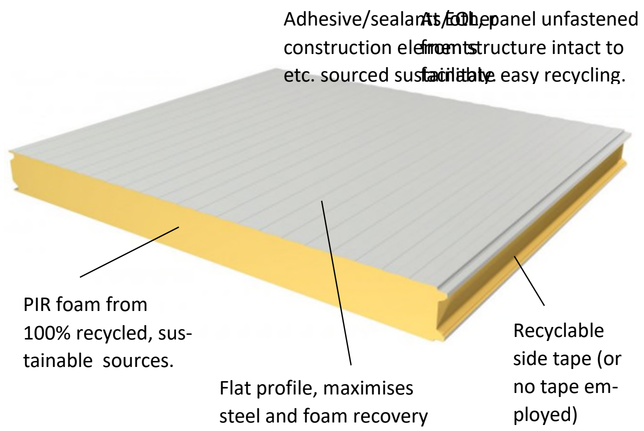

Figure 4. High level overview of characteristics of prototype panel.

As noted earlier, roof panel designs typically employ trapezoid ribbing to improve structural strength (see figure 5). Other designs may feature embellishments (waves or faux slate effects) or other non-functional designs to satisfy architectural requirements. These features will complicate removal of the steel during the ripping process outlined previously and would be discouraged when designing for circularity (These points will be raised with the stakeholders and customers during the customer experience reporting under WP2.3).

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Figure 5. Example of installed roofing panels featuring trapezoidal crowns (visible as ribbing running down the length of the panel).

To this end, the favoured design for roof panels would feature a flatter profile without compromising performance. Flat profile KS panels can be employed as roofing panels but require sealing membranes and other additional materials that would effectively create more waste during deconstruction – waste that is not amenable for recovery and recycling. Therefore, the most suitable prototype design in this case would be a flattened profile panel with minimal side crowns and overlap to allow weather sealing. The profile of a prototype panel is shown below in figure 6, compared with a standard KS1000RW roofing panel and a photo of the proposed prototype top sheet is given in figure 7. In addition to facilitating easier steel removal and foam recovery, other minor benefits from using a flatter profile would include easier and more efficient stacking of both foam and steel for storage and transport prior to reprocessing.

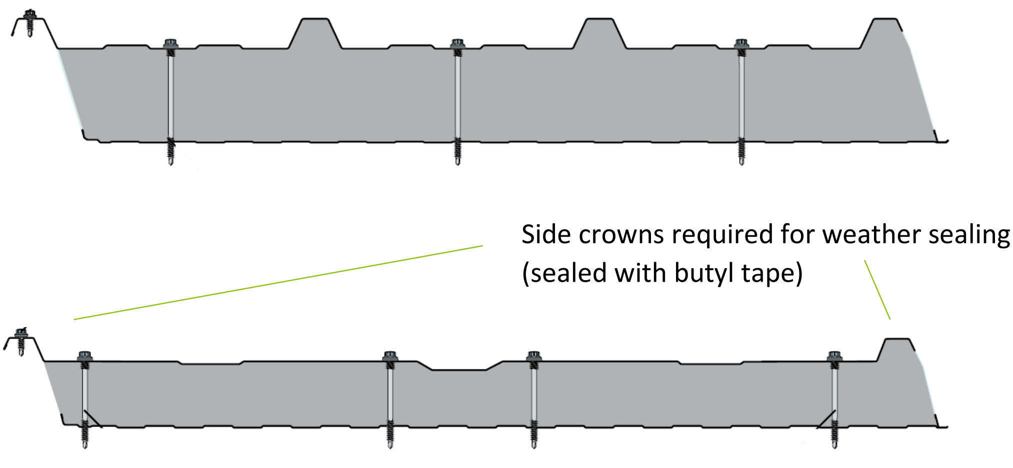

Figure 6. Profile of panel designs. The upper design (KS1000RW) features crown trapezoids while the prototype has a much flatter profile. Fasteners are also shown to demonstrate how the panels are mounted to the structure (see appendix for more detail on construction methods)

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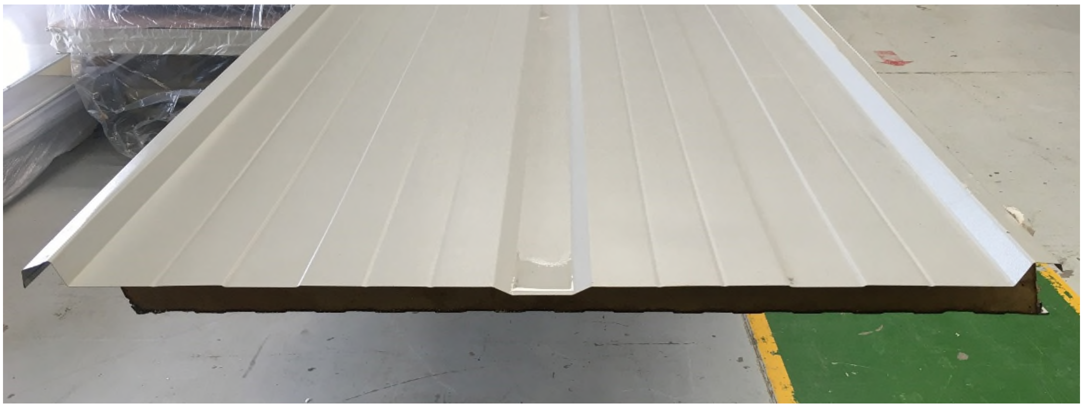

Figure 7. The flat profile steel sheet of the prototype panel.

While employing flat profiles in the prototype will facilitate recovery and recycling, it should be noted that removal of the crowns will likely result in reduced rigidity and structural strength of the panel and this would need to be factored into the design of the building.

3. Conclusion

Current panel designs and materials were evaluated in terms of their ease of recovery and recycling and this formed the basis for the prototype panel design. The removal of the steel sheets from the foam can be accomplished with relative ease, whether using saws or physical methods of ripping the steel from the panel. When employing the ripping method, the steel would consistently separate from the foam right at the join, with only a thin residue of foam remaining on the steel – the main bulk of the material remaining as solid block. The PP/PE side tape is required for current manufacturing processes – the best method at present is to remove the tape via bandsaw. In terms of prototype design, panels with flatter designs will be favoured as these are easier to dismantle and allow for maximum recovery of the foam. For roofing panels, which typically employ crowns to improve structural strength, this may require a trade-off of strength to facilitate easier recycling, and this will be further assessed going forward. Finally, three alternative construction methods were investigated. The current method of fastening panels to purlins was found to be amenable for demounting and recovering panel for recycling, however one of the other methods (dubbed the panel rail system), while developed for temporary structures, may also be suitable for permanent builds. These methodologies will be investigated further and form part of the stakeholder engagement in task 2.3.

The project work leading to this deliverable has investigated in close interaction with the recycling technology development, the influence of additives/ raw materials on the smart pyrolysis / chemolysis depolymerization. Based on these results and the insight from the recycling processes, new recipes and polyols were developed. The foams that were produced on the basis of the new developed formulations, will be tested in the frame of the recycling-related work. These results will show if these formulations can increase the recyclability. The results of these tests will be reported D4.3 "Procedure of the chemolysis and the separation of amines and polyols at 250 ml scale and pressure) for the chemolysis process including separation of amines from polyol at typical lab-scale eg. 250 mL" in M36. Then also results of the recycling of the new foams will be available.

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Accompanying video timings:

Event	Time (min)
Panel installation	0 – 1:12
Panel deconstruction	1:12 – 3:02
Fastener washer removal	3:03 – 3:10
Steel ripping (manual)	3:10 – 3:46
Side tape trimming	3:46 – 4:00

4. Appendices

Installation and dismantling procedures:

To facilitate transport, dismantling and recovery of the foam, steel and other elements, the panels need to be taken down in a non-destructive manner: damage to the panels will greatly complicate the recycling process.

Current installation methods generally involve fastening panels to a steel structure. The exact method followed will vary from build to build but a common methodology involves fitting the panels to steel purlin frame structure as shown in figure 8 (the full process is referenced below (Kingspan, 2022). The accompanying video also provides a quick demonstration of this process (installation: from start; dismantling from 1.12 min), it can be seen that panels can readily be taken down intact prior to transport and recycling.

Advantages:

- Well developed, mature method.
- secure fit and long-life performance.
- When dismantling at end-of-life, fasteners, flashings, panels and finally the structure can be removed and sorted for recycling.

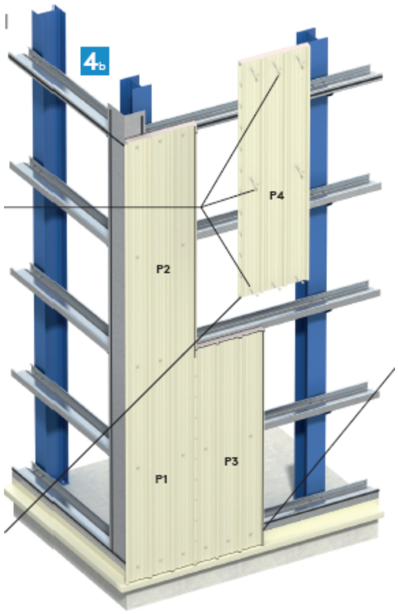

Figure 8. Typical installation of panel during construction.

Disadvantages:

- the time and effort involved in removing fasteners, flashings and other elements.
- Safe panel removal (both from H&S perspective and avoiding damage to panels).

To this end, alternative building methods were considered and compared with these existing methods.

Hung panels:

One approach considered was to develop panels that could be hung to the steel frame rather than fastened. This method was considered more as a means of preventing damage to the panel (i.e.

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fasteners bolted through the foam and steel of the panel). This would in theory allow the panel to be recovered and reused with ease. Panel designs facilitating this approach were considered but ultimately, this approach was deemed too impractical. Unfortunately, hanging the panel in this manner would require it to be reinforced with internal bolts (see fig 9a + b below) – greatly complicating steel removal and recycling of the panel. Mounting brackets would still be needed (fig 8c) so this method did not simplify the process either. It is possible this method may suit temporary structures where multiple reuse of panels would be possible but we do not consider it suitable for permanent builds or where the main goal is to facilitate panel recycling and recovery.

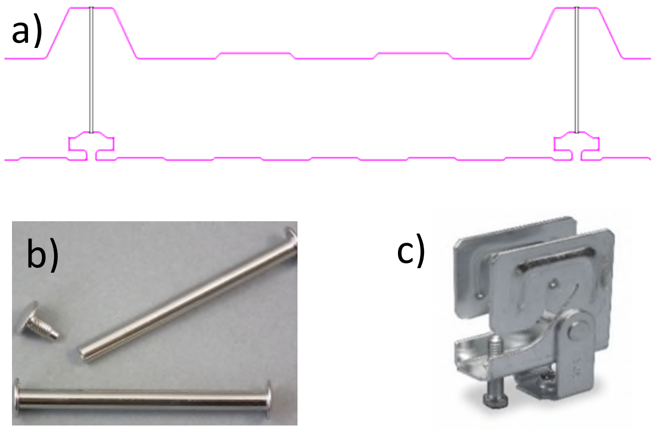

Figure 9. Schematic of panel for hanging mounting (a). Internal bolts (b), mounting bracket (c).

Panel rail system:

Another method of mounting panels involves the use of panel rails in the structure to hold the panels in place. Rather than being bolted to the building frame using fasteners, the panels are slotted into the upright beams in the build frame and either raised or lower into place as required. Note that other building features (windows, doors, etc.) can also be incorporated using this modular construction method. This method allows for rapid build and deconstruction and has the advantage of requiring minimal use of fasteners. Currently employed in temporary/semi-permanent structures (Big Space Solutions, 2023), and regulatory and other requirements would need to be assessed. Nevertheless, this build method will be assessed by internal and external stakeholders under task 2.3 and beyond to determine if it is feasible for permanent structures.

Figure 10. Structure incorporating panels mounted using vertical guide rails.

Advantages:

- Rapid construction and deconstruction method
- Suits modular, functional construction.

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Disadvantages:

- More suited to temporary builds.
- Long term performance and regulatory requirements would need to be addressed.

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References:

video metal panel

Video metal panel (link to project website)

Kingspan (2022) *Quadcore KS1000RW Downloads*, available at https://www.kingspan.com/gb/en/products/insulated-panels/wall-panels/quadcore-ks1000rw-wall-panel/?s=d, accessed Feb 2023

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